MATRICULATION AND SECONDARY
EDUCATION CERTIFICATE EXAMINATIONS
BOARD

ADVANCED MATRICULATION LEVEL
2021 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	I
DATE:	4th October 2021
TIME:	4:00 p.m. to 7:05 p.m.

A list of useful formulae and equations is provided. Take the acceleration due to gravity $g = 9.81\,\mathrm{m\,s^{-2}}$ **unless otherwise stated.**

SECTION A

Attempt all EIGHT questions in this section. This section carries 50% of the total marks for this paper.

1. Three teams A, B and C, are playing a game of tug of war where each team is pulling a rope with the forces F_A, F_B and F_C respectively. The ropes are tied together in one central knot as shown in Figure 1. Assume each pulling force exerted by each team to be non-zero.

   a. Explain why a force is considered to be a vector quantity. (1)

   b. Give **ONE** example of a scalar quantity. (1)

   c. Is it possible for the central knot to remain stationary while all teams are pulling the rope? Justify your reasoning. (3)

   d. Determine the necessary conditions for the resulting direction of movement of the knot to be along the rope of team B. (1)

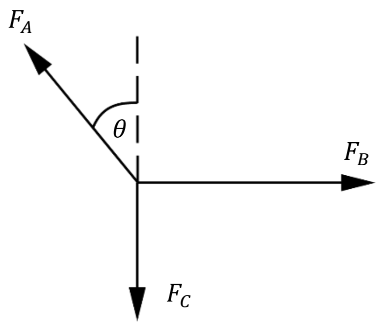

Figure 1

   e. Determine the resulting magnitude and direction of the force on the knot when $F_A = 500\ \mathrm{N}, F_B = 300\ \mathrm{N}, F_C = 200\ \mathrm{N}$ and $\theta = 30\ °$. (4)

(Total: 10 marks)

2. A $1\ \mathrm{kg}$ block travelling at a constant speed of $3\ \mathrm{m\,s^{-1}}$ collides into a stationary $2\ \mathrm{kg}$ block. After collision, the $1\ \mathrm{kg}$ block bounces backwards while the $2\ \mathrm{kg}$ block propels forward. Assume the collision to be perfectly elastic.

   a. Distinguish between perfectly elastic collisions and inelastic collisions. (2)

   b. Which physical quantity is conserved in both perfectly elastic and inelastic collisions? (1)

   c. Show that the following condition must hold:

   $$9 = {v_1}^2 + 2{v_2}^2$$

   where v_1 and v_2 represent the speeds of the $1\ \mathrm{kg}$ and $2\ \mathrm{kg}$ blocks respectively. (2)

   d. Hence, determine the resulting speeds of **both** blocks. (5)

(Total: 10 marks)

3. A child claims that she can rotate a glass of water in a vertical plane fast enough that no water is spilt. The glass is filled with $50\ \mathrm{g}$ of water and is rotated in a vertical circle of radius $35\ \mathrm{cm}$.

   a. Sketch a free body diagram indicating all forces acting on the water when the glass is at its highest position. (3)

   b. Determine the minimum angular speed required so that no water is spilt. (3)

   c. At this speed, how long would the glass of water take to complete one full revolution? (1)

   d. The child can rotate the glass at a maximum of $1.5\ \mathrm{rev\ s^{-1}}$. Determine whether this is fast enough to avoid spilling any water. (2)

   e. Does the amount of water present in the glass affect the child's ability to not spill any water if a maximum rotational speed of $1.5\ \mathrm{rev\ s^{-1}}$ is maintained? Explain your reasoning. (1)

(Total: 10 marks)

4. A trapdoor system illustrated in Figure 2 is designed such that the trapdoor opens once a certain weight threshold is reached. It consists of a hinged uniform beam $1.5\ \mathrm{m}$ long and having a mass $500\ \mathrm{g}$. A cable is attached to the beam's end making an angle of $60°$ to the horizontal. The cable breaks once a tension force of $15\ \mathrm{N}$ is reached. Balls of different masses are pushed along the length of the trapdoor.

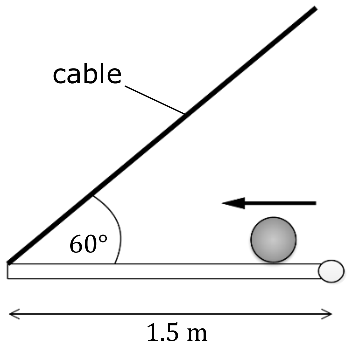

Figure 2

   a. State the conditions for a system to be in mechanical equilibrium. (2)

   b. Identify, giving reasons, the location of the ball on the beam which causes the cable to experience the largest tension. (3)

   c. Find the smallest mass that would cause the cable to break. (3)

   d. Describe how the angle that the cable makes with horizontal can be changed so that the trapdoor can support heavier masses. (2)

(Total: 10 marks)

5. A heater is made up of a resistance wire that has a temperature coefficient of resistance $0.00393\ °\mathrm{C}^{-1}$. The heater works optimally at $220\ \mathrm{V}$ with a power rating of $1.5\ \mathrm{kW}$. The resistance of the wire at $20\ °\mathrm{C}$ is $10\ \Omega$.

   a. Determine the resistance of the wire at the optimal working rating of the heater. (2)

   b. Hence, determine the temperature of the wire at the optimal working rating. (2)

   c. If another identical wire is connected in series such that the two wires now serve as the heating element, calculate the resistance of **each** wire needed to maintain optimal working operation and determine the temperature of the wires in this case. (2, 1)

   d. If the two wires were connected in parallel, what would this temperature be? (3)

(Total: 10 marks)

6. Two batteries, one with e.m.f. $2\,\text{V}$ and internal resistance $1\,\Omega$ and the other with e.m.f. $3\,\text{V}$ and internal resistance $2\,\Omega$, are connected in series with an external resistance R as illustrated in Figure 3.

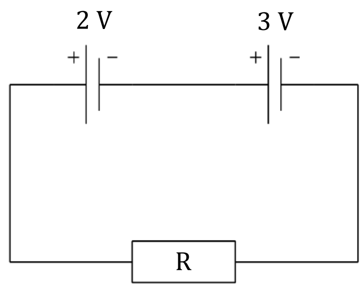

Figure 3

a. Define electromotive force. (1)

b. Obtain an expression for the current flowing through the circuit as a function of R. (3)

c. Show that the efficiency η of the circuit is given by $\eta = \frac{R}{3+R} \times 100\%$. (4)

d. Sketch a plot of η against R. (2)

(Total: 10 marks)

7. From data gathered during a photoelectric effect experiment, a graph of the maximum kinetic energy of the emitted electrons against the incident light frequency f shone onto the photoelectric material was plotted as shown in Figure 4.

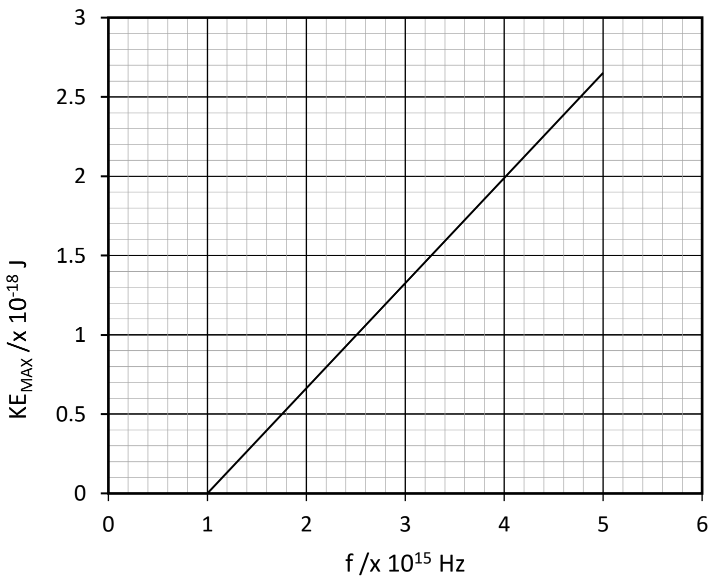

Figure 4

a. Explain why the graph is linear. (1)

b. What do the gradient and x-intercept signify? (2)

c. Explain why no data points were obtained for frequencies smaller than the x-intercept. (2)

d. Determine the work function of the material in Joules. (2)

e. Determine the wavelength of the incident light required to knock off electrons at a maximum speed of $4.43\ \text{m}\,\text{s}^{-1}$. (3)

(Total: 10 marks)

Please turn the page

8. A timer light circuit is used to light a high power led bulb at different times during the day and at different brightness. The led bulb operates at $9\,\mathrm{V}$. The current-time graph in Figure 5 shows how the current in the led bulb changes over a 24-hour time period.

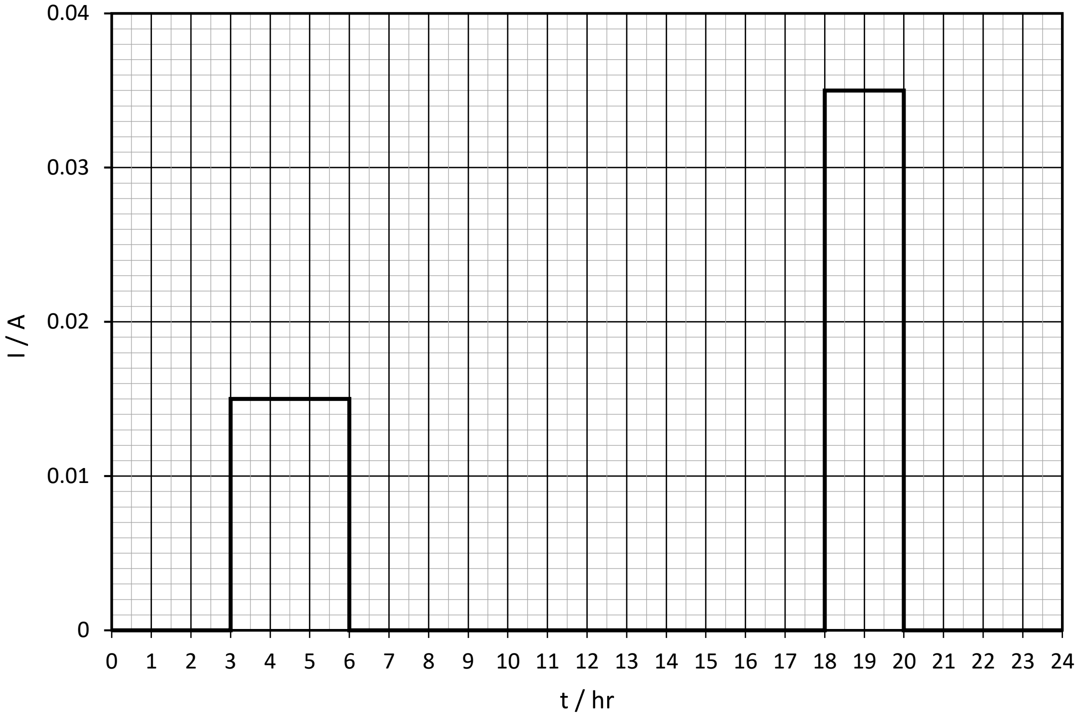

Figure 5

a. Describe how the led bulb's brightness changes over this period. (2)

b. Sketch a charge-time graph illustrating the total amount of charge that passed through the circuit over this 24-hour period. The sketch must include adequate values. (5)

c. The battery powering the circuit stores $550\,\mathrm{mAh}$ of charge. Determine the maximum number of whole days it can continue to operate the led light bulb before it needs to be replaced. (3)

(Total: 10 marks)

SECTION B
Attempt any FOUR questions from this section. Each question carries 20 marks. This section carries 50% of the total marks for this paper.

9. a. A student wishes to investigate the elastic properties of a rubber band.
   i. Describe an experiment the student could carry out to investigate such properties. Your description should include:
      - list of apparatus; (2)
      - well labelled diagram; (2)
      - a detailed procedure; (3)
      - data to be recorded; (1)
      - a suitable graph to be plotted. (2)
   ii. State **TWO** results from the experiment about the elastic properties of a rubber band. (2)
   iii. State **ONE** important necessary precaution for the student to carry out the experiment correctly. (1)

   b. A truck is towing a $1050\,\mathrm{kg}$ car up an inclined $35°$ hill using a $3.5\,\mathrm{m}$ long steel cable of Young's modulus $1.8 \times 10^{10}\,\mathrm{Pa}$ and diameter $1\,\mathrm{cm}$. Assume that the cable is parallel to the incline and that the truck is moving at a constant speed. Ignore any frictional forces.
   i. Determine the extension of the wire. (5)
   ii. Explain how the thickness of the wire will affect the strain in the cable. (2)

(Total: 20 marks)

10. Three wires X, Y and Z, each composed of a different material but of the same cross-sectional area of $3 \times 10^{-6}\,\mathrm{m}^2$, are being tested by connecting them to an electrical power supply and tabulating their corresponding currents. The table below also shows the drift velocity in the wires. In the case of wire Y, no current could be detected.

Table 1

Wire	X	Z
Current/A	1	20
Drift Velocity/$\mathrm{m\,s^{-1}}$	4.2×10^{-5}	9.2×10^{5}

   a. Determine the number of charge carriers per unit volume for wires X and Z. (2)

   b. Based on the information given, and the results obtained in part (a), identify which of the three wires is the conductor, the semiconductor, or the insulator. Give reasons for your answers. (3)

   c. Explain the difference between an extrinsic and intrinsic semiconductor. (2)

   d. Explain the nature of the conduction, valence, and forbidden bands. (3)

   e. Sketch an energy band diagram for a conductor, an insulator and an intrinsic semiconductor at low temperatures. (2, 2, 2)

   f. Using band theory, describe how the conductivity of an intrinsic semiconductor changes once its temperature is increased to relatively high temperatures. (3)

   g. Compare the conduction electron population against the hole population in an intrinsic semiconductor once conduction takes place. (1)

(Total: 20 marks)

Please turn the page.

11. a. A company is testing their $600\,\mathrm{g}$ basketball bouncing properties by releasing it from some initial height and observing how the height changes with time with every bounce. A plot of the potential energy against time t is shown in Figure 6.

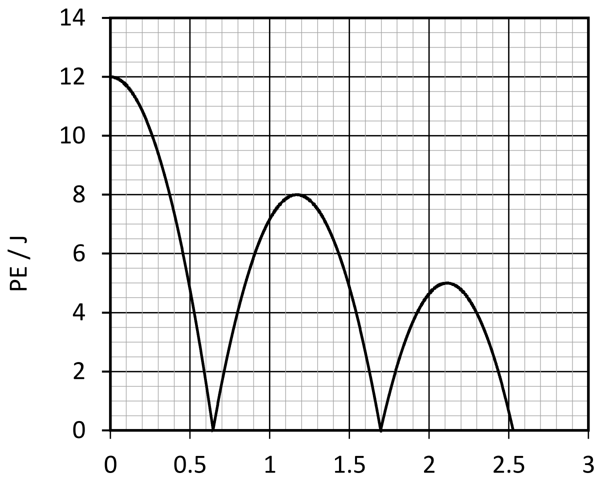

Figure 6

i. State the principle of conservation of energy. (2)

ii. Does the graph imply a violation of this principle? Explain your reasoning. (2)

iii. Use the graph to determine the velocity of impact just before it hits the ground for the second time. (3)

iv. Sketch a graph of the kinetic energy against time for the given time cycle. (4)

v. If the same experiment was conducted on the moon, would the potential energy graph change? Explain? (2)

b. A child on a skateboard of combined weight $750\,\mathrm{N}$ is playing on a frictionless ramp. Starting from rest, the centre of gravity of the combined boy and skateboard system falls a height of $3\,\mathrm{m}$ on the left-hand side of the ramp. It is followed by a $2.5\,\mathrm{m}$ long horizontal rough surface exhibiting a constant frictional force of $400\,\mathrm{N}$ and a high frictionless ramp on the right side, as shown in Figure 7.

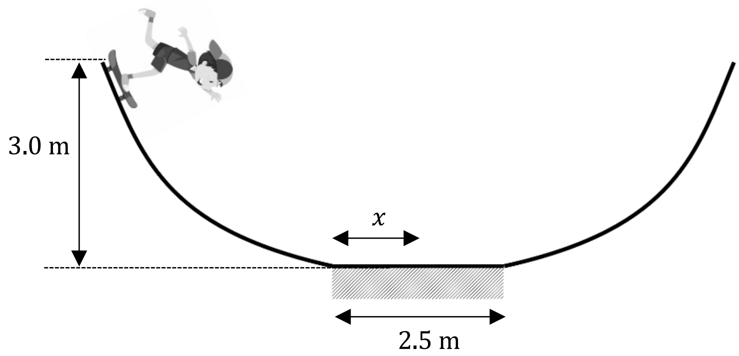

Figure 7

i. Determine the maximum height reached on the opposite vertical ramp. (4)

ii. If the child continues to move side to side without inputting any work, determine the distance x where the child stops. (3)

(Total: 20 marks)

12. A worker is attempting to push over a uniform $10\,\mathrm{kg}$ tyre of diameter $40\,\mathrm{cm}$ against a $10\,\mathrm{cm}$ high kerb. Initially, they pull the tyre from its centre A with a constant pulling force F as shown in Figure 8.

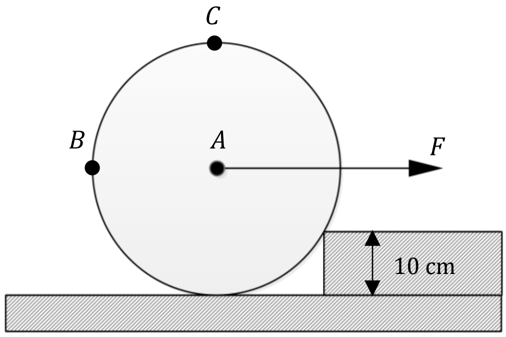

Figure 8

a. Determine the minimum force required to just lift the tyre off the ground. (5)

b. For this minimum force, determine the reaction force of the kerb onto the tyre just as the tyre loses contact from the ground. (4)

c. Does this reaction force remain the same once the tyre is on the kerb? Explain. (1)

The worker now pushes the tyre from point B, on the leftmost side of the tyre.

d. Would the minimum force required be different from that obtained in part (a)? Explain your reasoning. (2)

Now, they decide to push the tyre from point C, at the topmost part of the tyre.

e. Determine the minimum force required to just lift the tyre off the ground in this case. (3)

f. Hence, determine which of the three scenarios requires the least amount of force. (1)

g. Focusing on pushing the tyre from point C, describe how the minimum force required to push the tyre over the kerb changes using:
   i. a heavier tyre of the same size; (2)
   ii. a larger tyre but of the same mass. (2)

(Total: 20 marks)

13. a. Rutherford's alpha scattering experiment has been pivotal to gain further understanding of the physical nature of an atom's nucleus.
   i. Describe the experiment to investigate the nature of gold atoms. Your description should include:
      - a list of apparatus; (2)
      - a well labelled diagram; (2)
      - a brief outline of the procedure; (2)
      - the main observation from the experiment. (1)
   ii. Discuss how this observation leads to **THREE** important conclusions regarding the physical properties of the nucleus. (3)

Question continues on next page.

b. A fallout bunker is designed to shield against highly energetic gamma radiation. The bunker is built using concrete. The concrete's absorption properties are being investigated by plotting the transmitted gamma radiation I as a fraction of the incident radiation I_0 against the concrete thickness x. The results are shown in Figure 9.

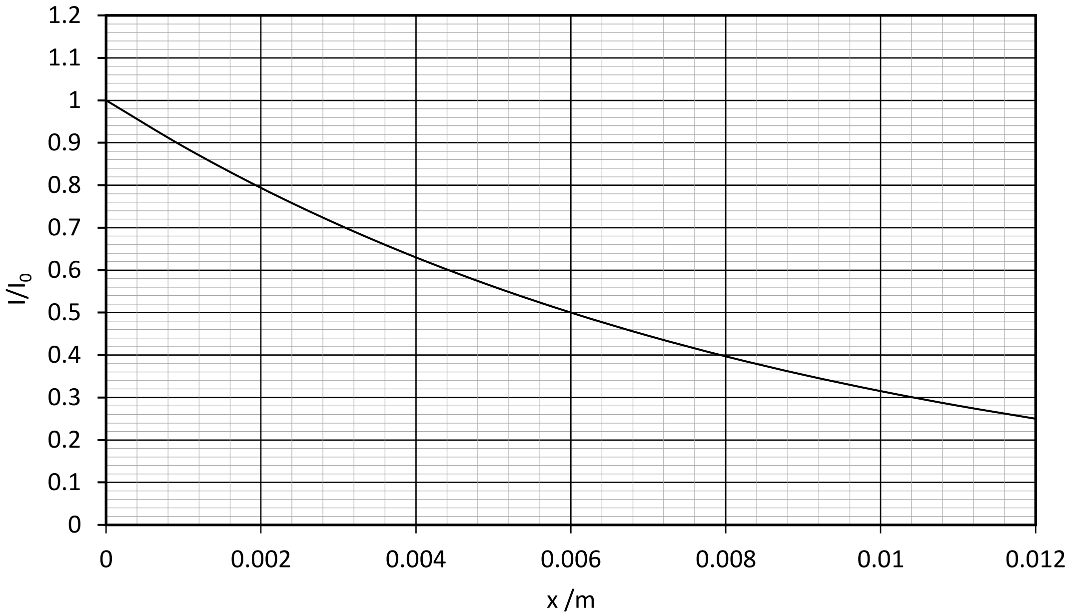

Figure 9

i. Define half-value thickness. (2)
ii. Use the graph to determine the half-value thickness value for concrete. (1)
iii. Hence, determine the required thickness of concrete to reduce the incident intensity by 95%. (5)
iv. To reduce the thickness of concrete required, a different material was proposed. Should its half-value thickness be larger or smaller than that of concrete? Explain your reasoning. (2)

(Total: 20 marks)

14. a. The circuit shown in Figure 10 can be used as a variable power supply. The 12 V battery has no internal resistance. A jockey slides along a uniform 1 m long wire of resistivity $2 \times 10^{-8}\ \Omega\text{ m}$ and cross-sectional area $2.5 \times 10^{-6}\text{ m}^2$.

i. Obtain an expression for the output voltage V_{out} in terms of x and R. (4)
ii. Is it possible for $V_{out} = 12\text{ V}$? Explain. (1)
iii. State the values of x which provide the minimum and maximum output voltage. Explain your reasoning. (2)
iv. Determine the position x, in terms of R, at which the voltage output is half that of the input. (1)
v. If the jockey is maintained at a fixed position x, explain what happens to magnitude of V_{out} when:
- R becomes very large; (1)
- the resistor R is removed from the circuit. (1)

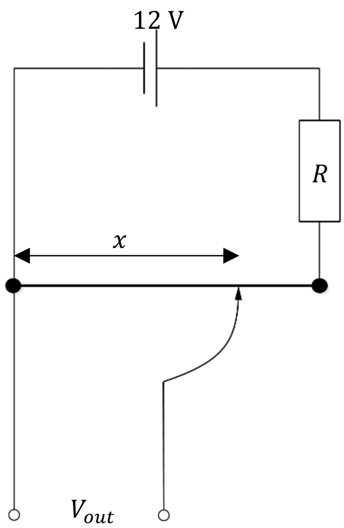

Figure 10

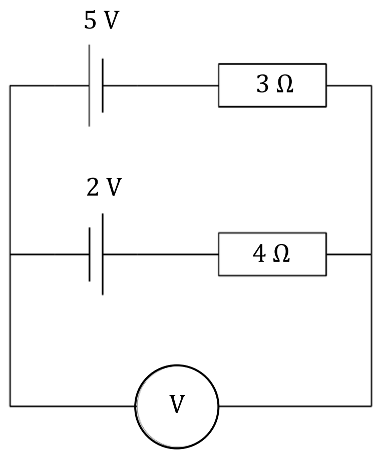

Figure 11

b. Consider the circuit shown in Figure 11. Determine the voltage read by the voltmeter if:
   i. voltmeter is ideal; (4)
   ii. voltmeter is non-ideal with resistance $100\,\Omega$. (6)

(Total: 20 marks)

15. a. A child pushes a large $20\,\mathrm{kg}$ spherical snowball of radius $50\,\mathrm{cm}$ so that it rolls from rest down an inclined snowy hill. The snowy incline has an angle of elevation of $40°$ and is $100\,\mathrm{m}$ high. The moment of inertia of a sphere is given by $I = \frac{2}{5}MR^2$ with M and R representing the mass and radius of the sphere respectively.
   i. Assuming that the snowball does not change in size and mass and that the snowball experiences pure rolling, determine the velocity of the snowball at the bottom of the incline. (5)
   ii. Hence, determine the time taken for the snowball to reach the bottom of the incline. (6)
   iii. Calculate the torque acting on the snowball. (3)

b. The angular speed of a $50\,\mathrm{kg}$ rotating disk of radius $30\,\mathrm{cm}$ is controlled by moving a $2\,\mathrm{kg}$ small mass along the disk's radius. When the mass is placed at the centre of the disk, the disk rotates at an angular speed of $20\,\mathrm{rad\,s^{-1}}$. The moment of inertia of the disk is $\frac{1}{2}MR^2$ with M and R representing the mass and radius of the disk respectively.
   i. Determine the disk's angular speed when the mass is moved $20\,\mathrm{cm}$ away from the centre of the disk. (3)
   ii. What will be the disk's angular speed once the mass is moved back to the centre of the disk? Explain your reasoning. (3)

(Total: 20 marks)

MATRICULATION AND SECONDARY
EDUCATION CERTIFICATE EXAMINATIONS
BOARD

L-Università ta' Malta

ADVANCED MATRICULATION LEVEL
2021 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	II
DATE:	5th October 2021
TIME:	4:00 p.m. to 7:05 p.m.

A list of useful formulae and equations is provided. Take the acceleration due to gravity $g = 9.81\ \mathrm{m\,s^{-2}}$ unless otherwise stated.

SECTION A
Attempt all EIGHT questions in this section. This section carries 50% of the total marks for this paper.

1. A student is provided with an electric kettle of known power, a timer, supply of water, a stirrer, a thermometer and a kitchen balance.

   a. Describe briefly how an approximate value for the specific heat c of water can be determined. (6)

   b. State the equation that is used to calculate the result. (2)

   c. State **TWO** main sources of uncertainty in this experiment. (2)

(Total: 10 marks)

2. A student heats $0.050\ \mathrm{kg}$ of naphthalene in a test tube. The temperature of the naphthalene is then measured at regular time intervals as the naphthalene cools down. The graph plotted for the cooling of the naphthalene is sketched below in Figure 1.

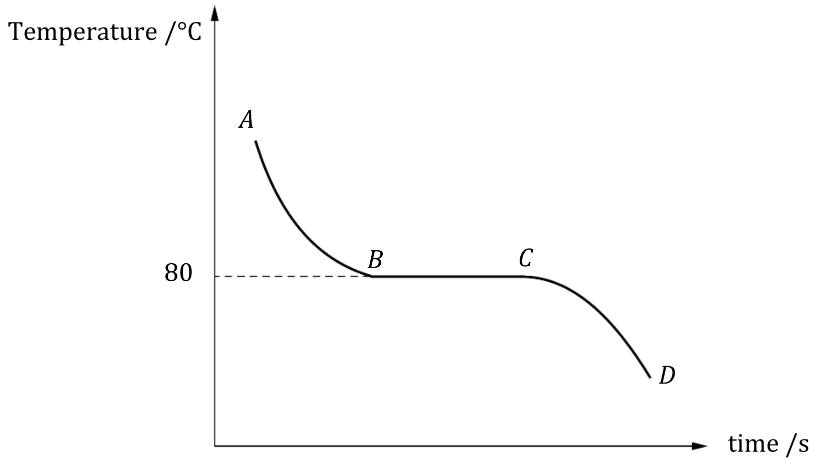

Figure 1

   a. Explain the shape of the graph between:
      i. AB; (1)
      ii. BC; (1)
      iii. CD. (1)

b. The student found that the rate of fall of temperature at point C of the graph was $0.17\ \mathrm{K\,s^{-1}}$. If the specific heat capacity of naphthalene when in the state corresponding to point C is $1300\ \mathrm{J\,kg^{-1}K^{-1}}$, what is the rate of loss of heat at point C? (2)

c. The rate of loss of heat of the test tube depends only on the temperature of its surface above that of the surroundings. The rate of fall of temperature at B was found to be $0.14\ \mathrm{K\,s^{-1}}$. Calculate the specific heat capacity of naphthalene when in the state corresponding to state B. (2)

d. The temperature of naphthalene remained constant at $80°\mathrm{C}$ for 11.6 minutes. Calculate the specific latent heat of naphthalene. (3)

(Total: 10 marks)

3. a. What is an ideal gas? (2)

b. Why is the concept of an ideal gas introduced in physics? (1)

c. Explain why the molar heat capacity of an ideal gas at constant volume, C_V, is less than the molar heat capacity at constant pressure C_P. (4)

d. Use the first law of thermodynamics to show that the internal energy, U, of an ideal gas under constant volume conditions is given by $\Delta U = C_V \Delta T$. (3)

(Total: 10 marks)

4. Edwin Hubble's observations showed that the Universe is expanding. The expanding Universe is one piece of evidence that supports the Big Bang theory.

a. State **ONE** other piece of evidence that supports the Big Bang theory. (1)

b. When Hubble's data is plotted, the graph shown below is obtained.

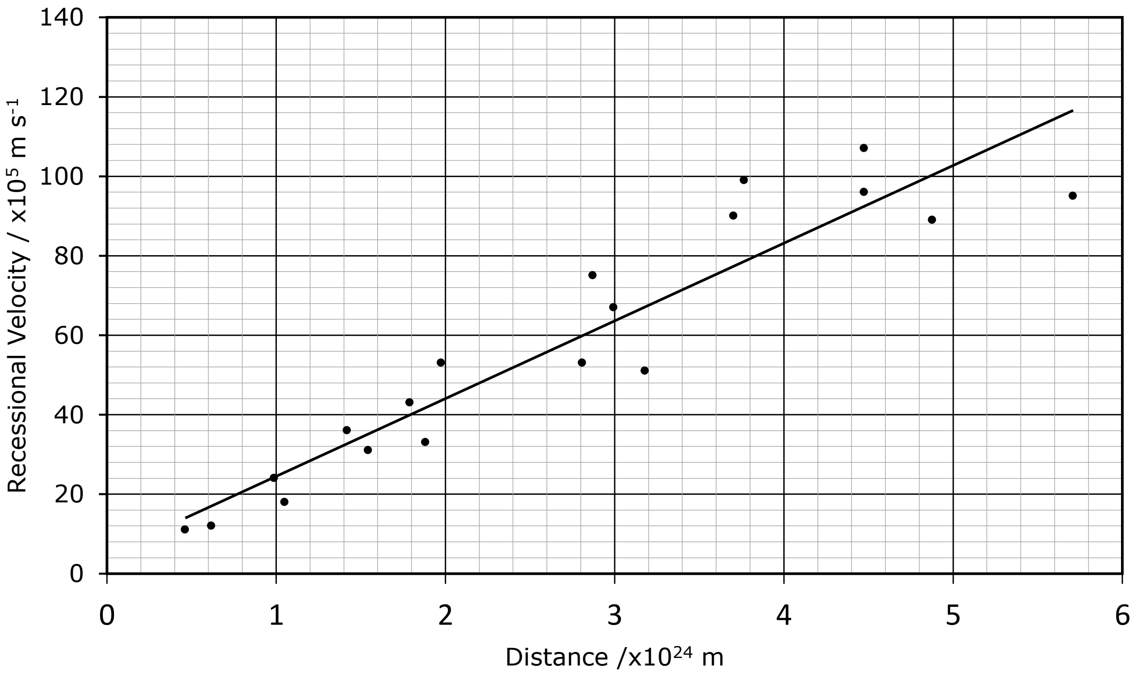

Figure 2

i. State Hubble's law. (2)

ii. Use the graph to obtain a value for Hubble's constant, and hence the age of the Universe in years. (4)

c. Hubble used the red Doppler shift of light from nearby galaxies to determine their velocity. Explain what is meant by red Doppler shift and state how this shift depends on the relative velocity of source and observer. (3)

(Total: 10 marks)

5. a. State the conditions required for a body to perform simple harmonic motion. (1)

b. A trolley, of mass m oscillates between two identical springs along a frictionless horizontal surface, as shown in Figure 3. The spring constant for each spring is k N m^{-1}. At one instant the midpoint, P, of the trolley has a displacement of x metres to one side of the centre of oscillation O.

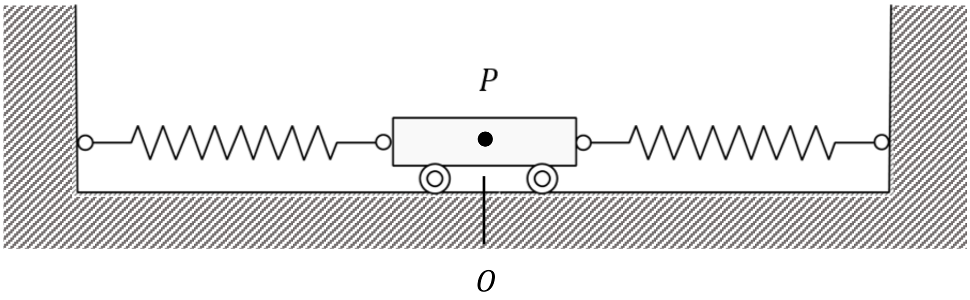

Figure 3

i. Show that the resultant horizontal force, F, acting on the trolley at this instant is given by $F = -2kx$. (2)

ii. Hence, starting from the equation for the acceleration $a = -\frac{4\pi^2}{T^2}x$ where T is the period of oscillation, show that $T = 2\pi\sqrt{\frac{m}{2k}}$. (3)

c. For one such trolley, the amplitude of the motion is 0.12 m. If the spring constant is 20.0 N m^{-1}, what is its maximum kinetic energy? (4)

(Total: 10 marks)

6. The diagram in Figure 4 represents a thick copper wire PQ resting on two conducting rails which are connected to a battery so that a current, I, flows through PQ. A magnetic field of flux density B acts perpendicularly into the paper.

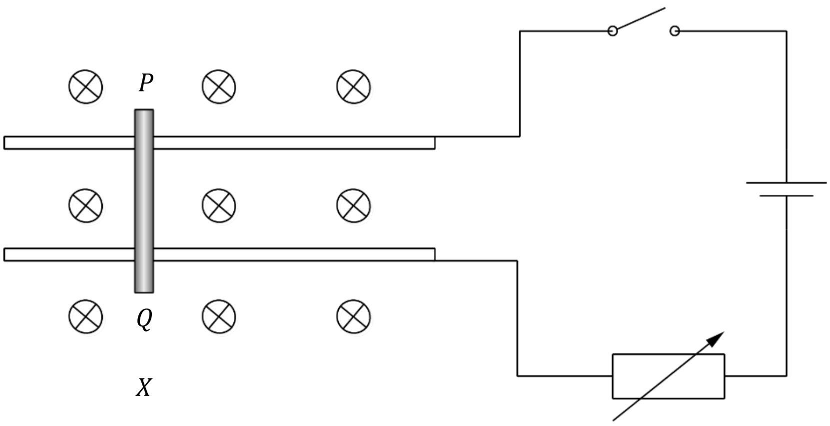

Figure 4

a. Draw the flux pattern, as seen from point X, of the combined magnetic field near the wire and state a reason why the wire moves when the current is switched on. (3)

Question continues on next page.

b. Does the force on the wire change in magnitude when the wire is moving? Explain your answer. (Neglect any frictional effects). (3)

c. The weight of the wire PQ is $0.050\,\mathrm{N}$ and the length of PQ between the rails is $0.060\,\mathrm{m}$ The current flowing through it is $4.0\,\mathrm{A}$. The rails are now tilted by $20°$ to the horizontal in such a way that the wire PQ remains stationary. By taking force components along the rails, find the flux density B of the magnetic field. (4)

(Total: 10 marks)

7. A rectangular coil $ABCD$ of N turns rotates at a constant angular velocity ω about the axis XY in a uniform magnetic field of flux density B as shown in Figure 5. The sides AB and AD are of length a and l respectively and the axis XY runs through the midpoints of sides AB and CD.

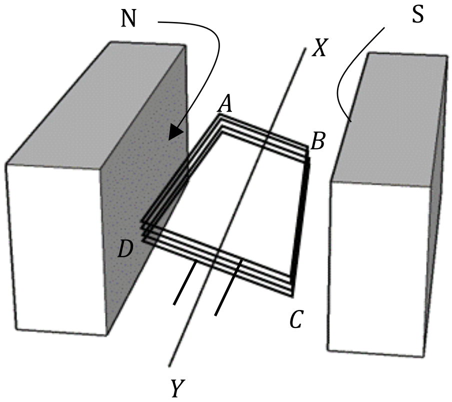

Figure 5

a. Explain why an e.m.f. is induced in the coil. (2)

The diagram in Figure 6 shows the coil from position Y when the plane of the coil makes an angle θ with the magnetic field.

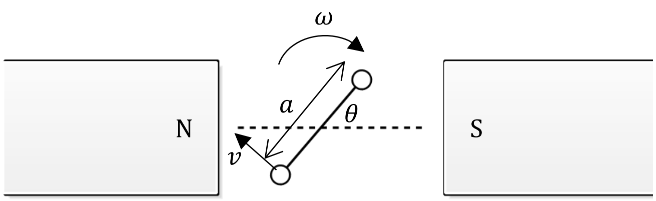

Figure 6

b. What is the velocity, v, of the side AD, in terms of ω and a, as the coil rotates about the axis XY? (1)

c. When a straight wire of length l moves with velocity v across a magnetic field of flux density B an e.m.f. $\varepsilon = Blv$ is induced in the wire.
   i. Write down the component of the velocity of side AD or BC which is perpendicular to the magnetic field and, hence, find the e.m.f. induced in one of these sides in terms of B, l, N, a, ω and θ at the instant shown. (3)
   ii. What is the e.m.f induced by sides AD and CD together? (1)
   iii. Write down an equation for the induced e.m.f. in the coil at time t, where t is the time corresponding to the angle θ. (2)
   iv. What is the maximum value, ε_{MAX}, of the induced e.m.f. in terms of B, N, A, and ω, where A is the area of the coil? (1)

(Total: 10 marks)

8. In an experiment to measure the speed of sound in air, a student connects a loudspeaker to a signal generator and places a microphone some distance in front of the loudspeaker. The output from the loudspeaker and the output from the microphone are connected to a double beam oscilloscope so that the two signals may be compared.

   a. Draw a diagram of the apparatus, including any apparatus not mentioned above, required to measure the speed of sound. (2)

   b. Assuming that the two signals have almost the same amplitude, draw diagrams to show the traces on the oscilloscope when the signals from the loudspeaker and microphone are:
      i. completely out of phase; (1)
      ii. in phase. (1)

   c. List the measurements which should be taken by the student in order to obtain a value for the speed of sound. (4)

   d. What should the student do to obtain a result as reliable as possible? (2)

(Total: 10 marks)

SECTION B

Attempt any FOUR questions from this section. Each question carries 20 marks. This section carries 50% of the total marks for this paper.

9. In a heat engine, 0.050 moles of an ideal gas are taken around the cycle in the $P - V$ diagram shown in Figure 7 below:

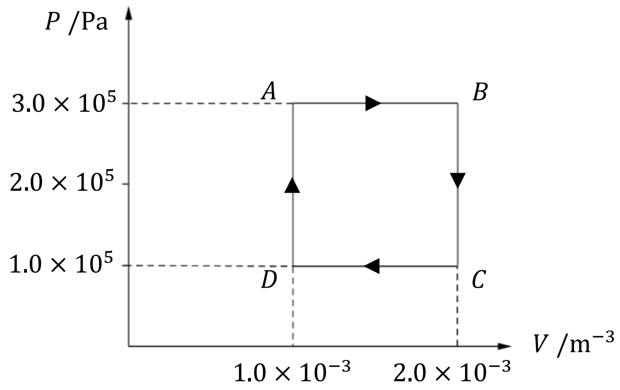

Figure 7

   a. Calculate:
      i. the work done during the expansion; (2)
      ii. the work done during the contraction; (2)
      iii. the net work done during the cycle. (1)

   b. Calculate the temperature at A and hence the temperatures at B and D. (7)

   c. The molar heat capacity at constant volume of an ideal gas is $12.5\,\mathrm{J\,mole^{-1}K^{-1}}$ while that at constant pressure is $20.8\,\mathrm{J\,mole^{-1}\,K^{-1}}$.
      i. Calculate the heat transfer during the processes DA and AB. (4)
      ii. Hence find the efficiency of the cycle. (2)

   d. If the heat engine goes through 12 cycles per second, what is its output power? (2)

(Total: 20 marks)

Please turn the page.

10. An uncharged conducting sphere is hung from a point P using a light nylon thread.

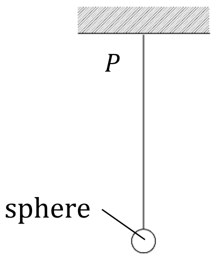

Figure 8

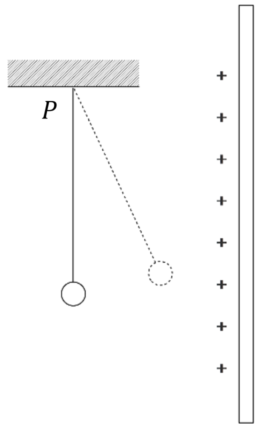

Figure 9

a. When a positively charged metal plate is brought near to the sphere, the sphere is attracted towards the plate.
   i. Explain why the uncharged sphere is attracted towards the plate. (3)
   ii. The gravitational potential energy of the ball in Figure 9 is greater than that in Figure 8. What is the source of this increase in energy? (2)
   iii. Copy Figure 9 and draw the electric flux pattern on the left side of the plate, while the sphere is being attracted. (2)

b. The sphere has a mass of 4.0×10^{-4} kg, and the nylon thread makes an angle of $10.0°$ with the vertical through P while the attraction is taking place. Calculate the electrical force on the sphere. (5)

c. The sphere is now touched momentarily on the side away from the charged metal plate. Explain what happens afterwards. (4)

d. The string finally comes to rest at an angle of $15°$. If the electric field strength at the position of the sphere is $1000\ \mathrm{V\,m^{-1}}$, what is the charge on the sphere? (4)

(Total: 20 marks)

11. Figure 10 shows two capacitors, P of capacitance $6.0\ \mu\mathrm{F}$, and Q of capacitance $12.0\ \mu\mathrm{F}$, connected in parallel. In Figure 11 the same two capacitors are connected in series.

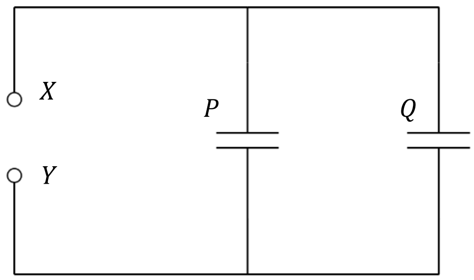

Figure 10

Figure 11

a. Calculate the total capacitance of the capacitors:
   i. when connected as in Figure 10; (2)
   ii. when connected as in Figure 11. (2)

b. A battery with an e.m.f. of $9.0\ \mathrm{V}$ is connected to the terminals X and Y. Calculate the:
   i. potential difference across **each** capacitor when in parallel and when in series; (5)
   ii. charge on **each** capacitor when in parallel and when in series; (4)
   iii. energy stored in **each** capacitor when connected in series. (2)

c. Both circuits are now disconnected. The $12.0\ \mu\mathrm{F}$ capacitor is charged by connecting it across the battery. The charged capacitor is disconnected from the battery and connected across another capacitor, X, of unknown capacitance. If it is found that the potential difference across the capacitors falls to $5.0\ \mathrm{V}$, what is the capacitance of capacitor X? (5)

(Total: 20 marks)

12. a. Explain what is meant by the Universal Gravitational Constant G and state why this constant is said to be universal and derive its units. (5)

b. In 1798, Cavendish determined the constant G by measuring the force between a lead sphere of radius $0.100\ \mathrm{m}$ and another lead sphere of radius $0.025\ \mathrm{m}$. The masses of the smaller and larger spheres were $0.746\ \mathrm{kg}$ and $47.8\ \mathrm{kg}$ respectively. Calculate the gravitational force between the two spheres when their surfaces were $0.0050\ \mathrm{m}$ apart. (3)

c. Cavendish obtained the value $G = 6.7 \times 10^{-11}$ in SI units. Use this value of G to calculate the mass of the Earth, given that the radius of the Earth is $6400\ \mathrm{km}$ and the acceleration of free fall, g, on its surface is $9.8\ \mathrm{m\ s^{-2}}$. (3)

d. The rotation of the Earth about its axis changes the value of the acceleration of free fall over the Earth's surface.
   i. State **THREE** other factors that cause variations in this value. Explain the effect on g of **each** of the factors mentioned. (6)
   ii. Assuming that the Earth is a uniform sphere, what is the difference between g at the poles and g at the equator due to the daily rotation? (3)

(Total: 20 marks)

13. Figure 12 shows a small slice of semiconducting material of width w and thickness t. A current I flows through the material as shown.

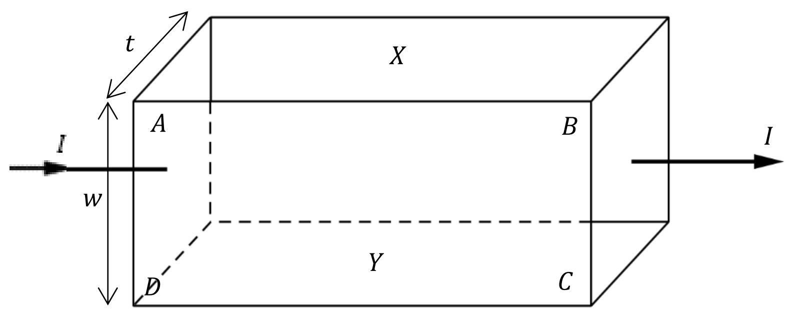

Figure 12

Question continues on next page.

a. When a magnetic field is applied across the material, into the face $ABCD$, charge carriers in the material will be affected and an electric field perpendicular to the direction of the magnetic field will be produced.

i. Assuming that the charge carriers are electrons, explain how the electric field is produced between face X and Y. (3)

ii. Write down equations for the magnetic force and electric force acting on **each** electron and hence show that the magnitude of the potential difference across the material is $V_H = Bvw$ where v is the drift velocity of the electrons. (3)

iii. It is known that the number of free electrons per unit volume in the semiconductor is $1.50 \times 10^{23}\ \mathrm{m^{-3}}$. If the thickness t is $0.20\ \mathrm{mm}$ and the potential difference across the faces X and Y is $0.0025\ \mathrm{V}$ when the current I is $50\ \mathrm{mA}$, calculate the flux density B of the magnetic field. (The charge on the electron is $1.60 \times 10^{-19}\ \mathrm{C}$). (6)

b. The slice is mounted so that it may be used as Hall probe in order to measure flux densities. Usually, the Hall probe is calibrated by using a known magnetic field.

i. Draw a circuit diagram to show how a solenoid may be connected together with an ammeter and power supply to produce a uniform magnetic field. (2)

ii. List the measurements that should be taken to calculate the flux density inside the solenoid. (3)

iii. Describe how the Hall probe may be calibrated using the solenoid. (3)

(Total: 20 marks)

14. a. The diagram shows a ray of light incident at an angle θ on a $45°$ right angled glass isosceles prism of refractive index 1.50. The ray of light hits at the midpoint of side AB of length $8\ \mathrm{cm}$. The prism lies on a liquid surface which, in turn, lies on a glass block. The light ray emerges from the liquid as shown in the diagram in Figure 13.

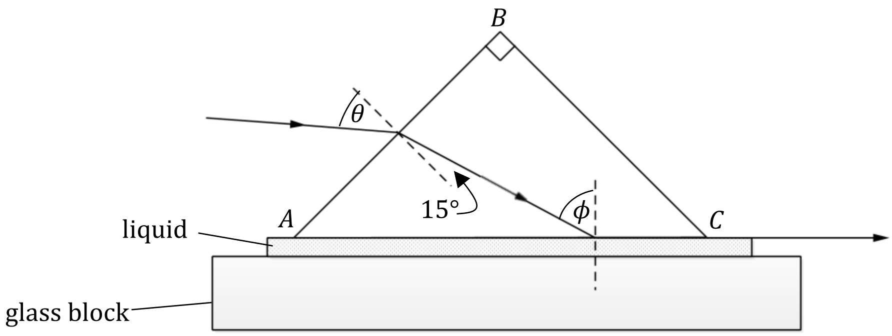

Figure 13

i. Calculate:

- the speed of light inside the prism; (2)
- the angles of incidence, θ, on the glass prism, and ϕ on the glass liquid boundary; (2)
- the refractive index of the liquid. (4)

ii. What is the minimum value that the angle ϕ can have? (2)

iii. Calculate the maximum angle of incidence θ that the incident light can hit the prism at the midpoint of side AB if the refracted ray is to hit the glass-liquid boundary AC. (4)

b. A coin, P, lies at the bottom of a beaker, as shown in Figure 14. A converging lens, L, of focal length $0.120\ \mathrm{m}$ is placed $0.200\ \mathrm{m}$ away from the coin. Water of refractive index 1.33 fills the beaker to a depth of $0.150\ \mathrm{m}$.

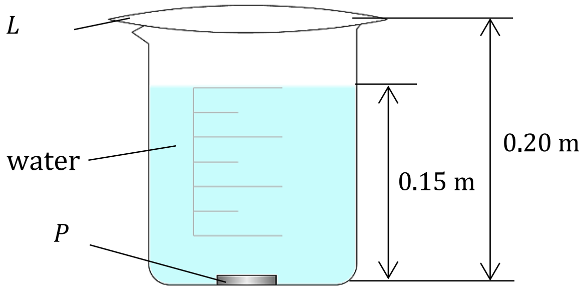

Figure 14

iv. Calculate the apparent depth of the coin. (2)

v. How far from the lens should a screen be placed so that a sharp image is formed on it? (4)

(Total: 20 marks)

15. For a diffraction grating of line spacing d which is placed normally to light of wavelength λ, the angle θ between the normal and the nth order image is given by the equation $d\sin\theta = n\lambda$.

a. Given a laser, a diffraction grating of known line spacing and a screen, describe how one would measure the wavelength of the light emitted by the laser with the least uncertainty possible. Draw a diagram of the set up showing appropriate dimensions. (7)

b. Sodium light with a wavelength of $5.89 \times 10^{-7}\ \mathrm{m}$, falls normally onto a grating of 5.08×10^{5} lines per metre. What is the highest order observable? (3)

c. A monochromatic light source illuminates two pinholes, some $3\ \mathrm{mm}$ apart, in a metal sheet. The pinholes are observed through an adjustable slit aperture. Explain, using appropriate diagrams, why

i. the two pinholes appear separate when viewed through the aperture from about $4\ \mathrm{m}$ away, the aperture being wide open. (4)

ii. there is a slit width, D, of the aperture below which the two pinholes can no longer be distinguished from the same distance. (3)

iii. if the two pinholes are illuminated by light of shorter wavelength, the two pinholes could be distinguished even when the slit width is less than D. (3)

(Total: 20 marks)

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

L-Università ta' Malta

ADVANCED MATRICULATION LEVEL
2021 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	III
DATE:	6th October 2021
TIME:	4:00 p.m. to 5:35 p.m.

Experiment: Investigating the linear expansivity of a metal tube.

Apparatus: beaker, mercury-in-glass thermometer, tripod, gauze wire, bunsen burner, NTC thermistor, multimeter, aluminium tube, optical lever with mirror, laser diode, metre ruler, stand and clamp, glass plate.

Diagram:

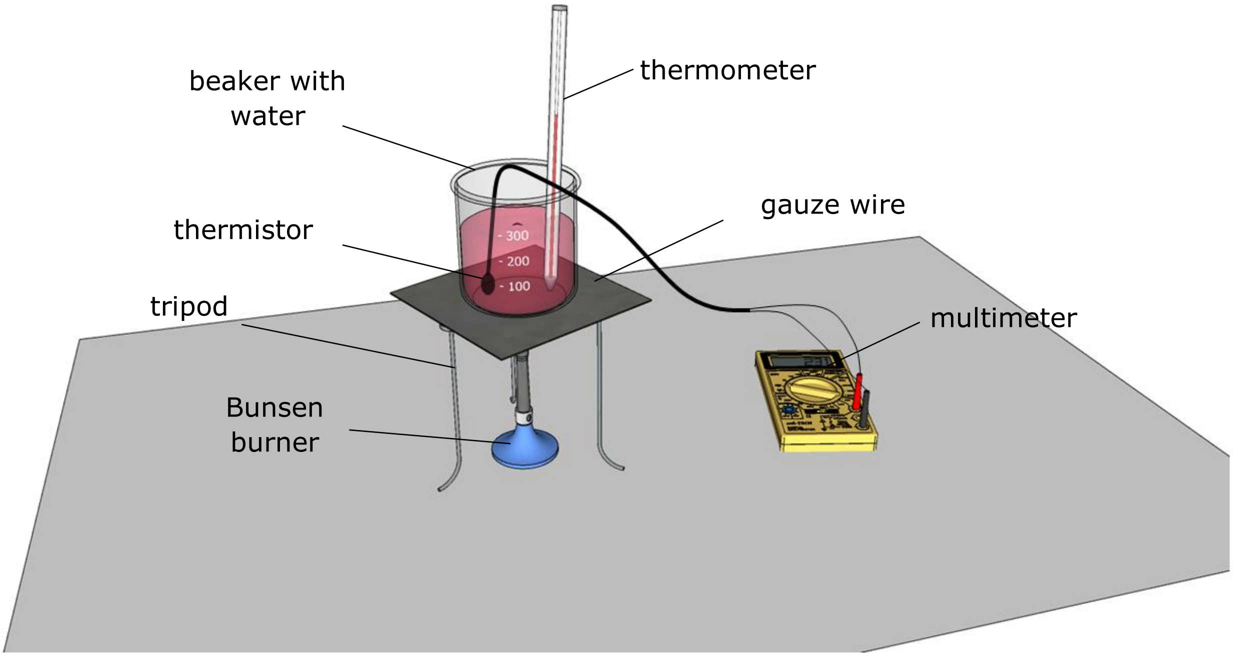

Figure 1 The experimental setup

Method – Part A:

1. The apparatus shown in Figure 1 was set up.

2. In this part of the experiment, a negative temperature coefficient (NTC) thermistor was calibrated with temperature.

3. The thermistor provided was a negative temperature coefficient thermistor. Explain what is meant by negative temperature coefficient thermistor.

____

____ (3)

4. One important characteristic of a thermistor is its "B" value. The B value is a material constant which is determined by the ceramic material from which the thermistor is made. Each thermistor material has a different material constant and therefore a different resistance versus temperature curve.

5. The multimeter was set to a range that gives an accurate reading of resistance and the liquid-in-glass thermometer was placed inside the beaker. The Bunsen burner was lit to heat the water in the beaker.

6. The resistance of the thermistor was measured as the temperature of the water rose.

7. The resistance R and the temperature θ read from the thermometer were recorded in Table 1.

Table 1

$\theta/°C$ ± 0.5	$R\ /\Omega$ ± 0.1	$\frac{R_0}{R}$	$\ln\left(\frac{R_0}{R}\right)$	T/K	$\frac{1}{T}\ /\mathrm{K}^{-1}$
38.5	2950.0				
49.0	1799.0				
59.5	1302.0				
68.5	1096.0				
82.0	626.0				
90.5	510.0				
99.5	365.0				

8. It is known that the resistance R of the thermistor is related to the temperature T in Kelvin by the expression.

$$\frac{1}{T} = -\frac{1}{B}\ln\left(\frac{R_0}{R}\right) + \frac{1}{T_0}$$

where R_0 is the resistance of the thermistor at a temperature of T_0. For this thermistor, $R_0 = 4890\ \Omega$ when $T_0 = 298.15\ \mathrm{K}$.

9. Work out and fill in the values of $\frac{R_0}{R}$, $\ln\frac{R_0}{R}$, T and $\frac{1}{T}$ in Table 1. (14)

10. Plot a graph of $\frac{1}{T}\ /K^{-1}$ on the y-axis against $\ln\frac{R_0}{R}$ on the x-axis. (10)

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11. Use the graph to determine the physical parameter B of the thermistor and write down its units.

____ (3)

12. Use the graph to determine the value of T_0 from the y-intercept and calculate the percentage difference from the known value for T_0.

____ (2)

13. Rewrite the equation in question 8 and substitute the value of B obtained in question 11, and $\frac{1}{T_0}$ obtained in question 12. This equation can now be used to determine the temperature when resistance values are known.

____ (1)

Method – Part B:

14. In this part of the experiment, the coefficient of linear expansivity of an aluminium hollow tube can be determined using an optical lever.

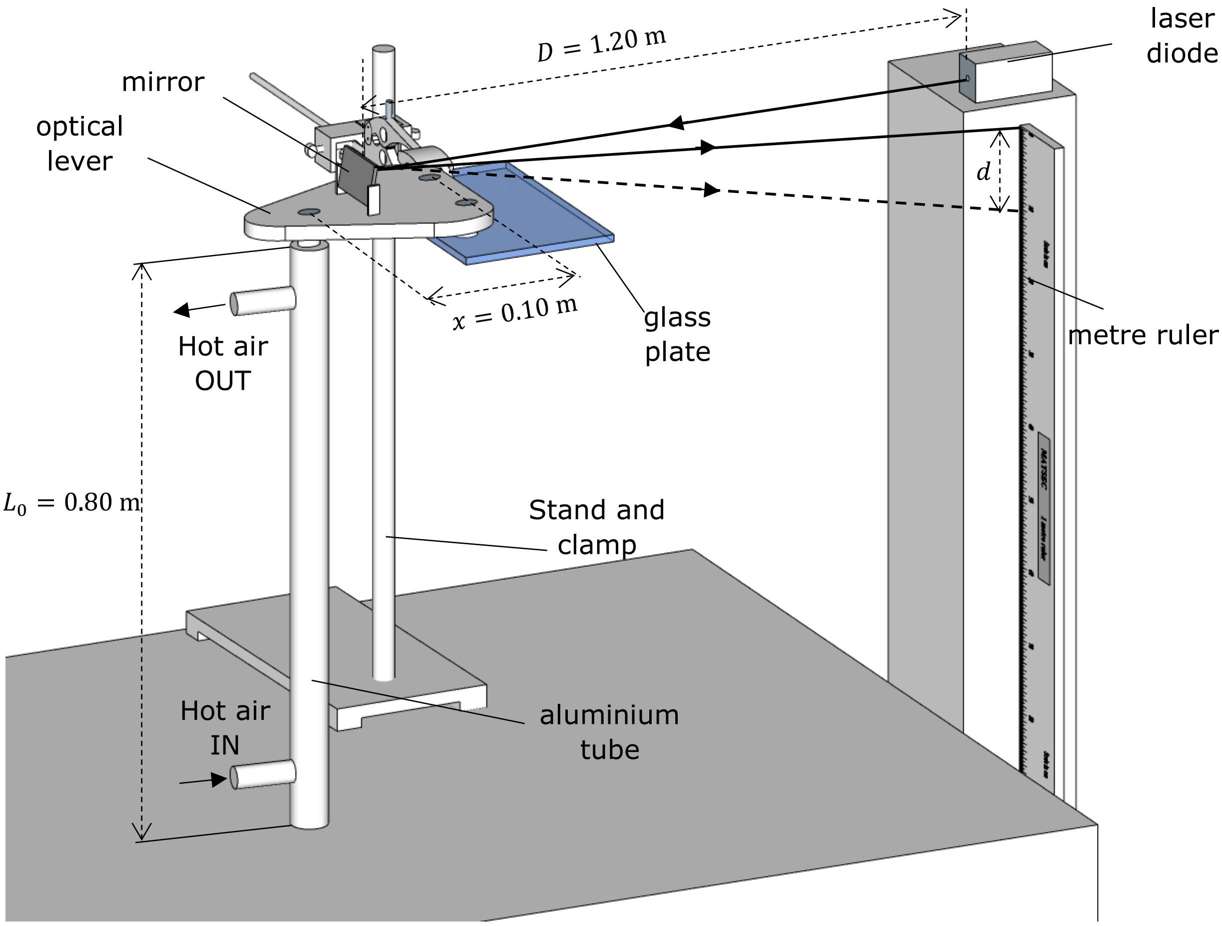

Figure 2

15. State the definition of the coefficient of linear expansivity. Explain any terms used.

____

____ (3)

16. In the setup shown in Figure 2, hot air at different temperatures was blown into the hollow aluminium tube which expanded during heating.

17. The linear expansion of the tube was determined by the optical lever. The optical lever consists of a rigid platform with an adjustable plane mirror attached to the platform. The optical lever has its rear leg on the top of the metal tube and the front legs on the fixed horizontal glass plate that is level with the top of the metal tube.

18. Light from a laser diode was shone on the mirror. As the metal tube expands, the rear leg of the optical lever was lifted upwards by the expanding aluminium tube. This changed the angle of the mirror and the reflected light spot from the laser moved downwards along the metre ruler.

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19. The temperature of the metal tube was determined by the resistance of the thermistor used in Part A, which was inserted into the tube.

20. The distance between the back and front legs of the optical lever is x. The distance between the mirror and the metre ruler is D. The distance the laser spot moves is d. The length of the tube is L_0 at the initial temperature T_i.

21. Table 2 summarises the measurements of T_i, L_0, x and D.

Table 2

T_i /K	298.15 K
L_0/m	0.80 m
x /m	0.10 m
D /m	1.20 m

22. At the initial temperature T_i, the optical lever was level and the mirror was adjusted to that laser spot hit the 0 cm mark on the metre ruler.

23. Readings for the resistance R of the thermistor and the distance d that the laser spot moved were recorded in Table 3.

Table 3

R /Ω ± 0.1	$\frac{1}{T}$ /K^{-1}	T /K	$\Delta T = T - T_i$ /K	d /m
1844.0				0.012
749.1				0.024
385.6				0.041
209.0				0.048
116.1				0.063
69.0				0.070
43.8				0.090
30.5				0.095
20.2				0.114

24. Use the expression derived in question 13 to work out the value of $\frac{1}{T}$ and T in Table 3. (18)

25. Hence, work out the values for ΔT. (9)

26. The displacement of the laser spot d is related to the change in temperature ΔT by the expression:

$$d = \frac{2\alpha D L_0 \Delta T}{x}$$

where α is the coefficient of linear expansivity.

27. Plot a graph of d on the y-axis against ΔT on the x-axis. (10)

28. Use the graph to determine the coefficient of linear expansivity of the aluminium tube.

____

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____

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____ (5)

29. State **ONE** source of error that could be present in the experiment and **ONE** corresponding precaution that could be taken during part B of the experiment.

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____

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____ (2)

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